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# SHEET EROSION ON INTERMOUNTAIN SUMMER RANGES

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## *THE AUTHOR*

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## ABSTRACT

Simulated rain was applied to small plots on seven mountain rangeland sites in Utah, Idaho, and Montana. Multiple regression equations were developed for each site relating the resultant erosion to cover characteristics, soil properties, and slope gradient. The magnitude of erosion was found to depend primarily on the proportion of the soil surface protected from direct raindrop impact by plants, litter, and (in some cases) stone. Soil organic matter favored stability of fine-textured soils, but apparently increased erodibility of sandy soils. The regression equations are presented in tabular and nomographic form to aid the land manager in the assessment of potential sheet erosion on sites similar to those studied.



## INTRODUCTION

Early detection of incipient erosion is necessary for efficient management of range-watersheds. The early stages of sheet erosion are much more difficult to recognize than the pedestals, rills, and gullies typical of advanced erosion. Yet, sheet erosion profoundly affects the range; productivity declines as fertile topsoil and humus are gradually lost. This loss can proceed undetected for years until its adverse effects on plant growth and infiltration capacity lead to the more obvious stages of erosion. Once the advanced stages are reached, regaining control of erosion is much more difficult than preventing excessive sheet erosion at the incipient stage.

Sheet erosion is usually caused by convectional rainstorms. These storms are characterized by many large raindrops falling at velocities ranging up to more than 20 miles per hour (Laws 1941). Upon striking bare soil these large drops detach particles from the soil mass and the resulting splash carries them as far as 2 or 3 feet from their original site. Since the rainsplash tends to move farther downhill than uphill, the net effect of rainsplash is downhill soil movement even in the absence of overland flow. If rivulets of overland flow are present, soil particles splashed into such rivulets are carried even farther downhill.

Soils vary in their susceptibility to erosion. Clays, particularly those that are tightly bound into large aggregates, tend to be difficult to detach. However, once detached, clays are easily transported and can be suspended and carried in overland flow for great distances. Sands are less cohesive and are easily detached but because of larger size are less easily transported and are not carried as far by overland flow unless it is rapid and turbulent.

Vegetative cover is the best practical protection against excessive sheet erosion because it breaks raindrop impact and favorably influences infiltration capacity. However, the amount of vegetative cover needed to achieve a given level of control of sheet erosion will vary with slope and soil properties because susceptibility to detachment and transportation vary with these factors.

To obtain maximum use of forage without risking excessive erosion, and to recognize potential erosion hazard, the range manager needs to know quantitative relations between vegetative cover and potential sheet erosion under diverse climatic, soil, and topographical conditions. At present, quantitative information on this subject is limited to a few geographical areas.

Osborn (1956) studied the effects of vegetative cover and soil on splash erosion on rangeland in Texas and Oklahoma and developed vegetative cover requirements to control splash erosion on various soil textures and plant species compositions in that area.

On the basis of simulated rain experiments on granitic soils in southern Idaho, Packer (1951) concluded that adequate control of summer storm runoff and erosion on wheatgrass (*Agropyron inerme*) range requires at least 70 percent ground cover of plants and litter and that bare openings should be no larger than 4 inches. Ground cover consists of plant basal area plus surface litter. On cheatgrass (*Bromus tectorum*) range, 70 percent ground cover is required also, but bare openings should be no larger than 2 inches. The effects of slope gradient, soil depth, soil porosity, and root abundance in the soil were also investigated but these effects were not great enough at this location to warrant their inclusion in the protection requirements.

On an aspen site in northern Utah, Marston (1952) found that ground cover of 65 percent or more was required for effective control of overland flow and erosion caused by storms having rainfall intensities in excess of 3 inches per hour.



Packer (1963) prescribed ground cover densities of at least 70 percent and soil bulk densities no greater than 1.04 g./cc. as necessary to maintain soil stability on the Gallatin elk winter range in south-central Montana.

Using a rainfall simulator on a subalpine cattle range in central Utah, Meeuwig (1965) found that soil erosion was more closely correlated with the proportion of soil surface protected from direct raindrop impact by plants, litter, and stone than any other measured variable. However, this relation between protective cover and soil erosion is strongly influenced by soil bulk density; the influence of cover is greatest at high bulk density and is least at low bulk density. If protective cover exceeds 85 percent, the amount of soil eroded is small, irrespective of bulk density.

The results of a study on the sheet erosional behavior of seven diverse summer range sites in Idaho, Montana, and Utah are presented in the following sections of this paper. This study was designed to augment the previously reported studies and to provide means for predicting sheet erosion potential under a variety of slope, soil, and cover conditions. Soil eroded from small plots (20 by 30.5 inches, or about 0.1 milacre in size) under simulated high-intensity rain was measured and related to slope gradient, weight and areal cover of vegetation and litter, and several soil properties.

## STUDY AREAS

The study areas are located on middle-to-high-elevation herbaceous rangelands (fig. 1). All such areas are grazed by livestock during the summer except Area 2 on the Davis County Experimental Watershed from which grazing has been excluded for more than 30 years. Following are details of each area:

1. *Great Basin Experimental Area* (GBEA), Manti-LaSal National Forest, central Utah. This is sheep range with a wide variety of grass and forb species. Soils are mostly silty clay loams and clay loams derived from sedimentary rock, predominantly limestone but containing some shale and sandstone. Elevations of study plots ranged from 7,000 to 10,000 feet; most were about 9,000 feet.
2. *Davis County Experimental Watershed* (DCEW), Wasatch National Forest, northern Utah. This area was the source of serious floods during the period 1923 to 1933. Much of this watershed was contour trenched and seeded to grass during the period 1933 through 1936. Grazing has been excluded since 1933. Soils are mostly silt loam and loam. Parent materials vary from metamorphic gneisses and schists to conglomerates, sandstone, and shales. Elevations of study plots were between 8,000 and 9,000 feet.
3. *Vigilante Experimental Range and Monument Ridge* in the Gravelly Range, Beaverhead National Forest, southwestern Montana. This is cattle and sheep range dominated by Idaho fescue (*Festuca idahoensis*) in many parts and by native forbs or seeded grasses such as crested wheatgrass (*Agropyron desertorum*) in others. Soils are mostly silt loam and silty clay loam derived from red shales, siltstone-shales, and glacial till. Elevations of study plots were between 7,000 and 9,500 feet.
4. *Diamond Mountain Cattle Allotment* near Flaming Gorge, Ashley National Forest, eastern Utah. This is an experimental grazing area where much of the native sagebrush-grass vegetation has been replaced with introduced grass species. Soils are loams and sandy loams derived from sedimentary rocks. Plots were at about 8,000 feet.
5. *Basalt* range north of Seven-Devils, Nezperce National Forest, central Idaho. Study plots in this area were located in grassy openings in open ponderosa pine stands. Soils are loams and silt loams derived from basalt. Most plots were near 5,000 feet.



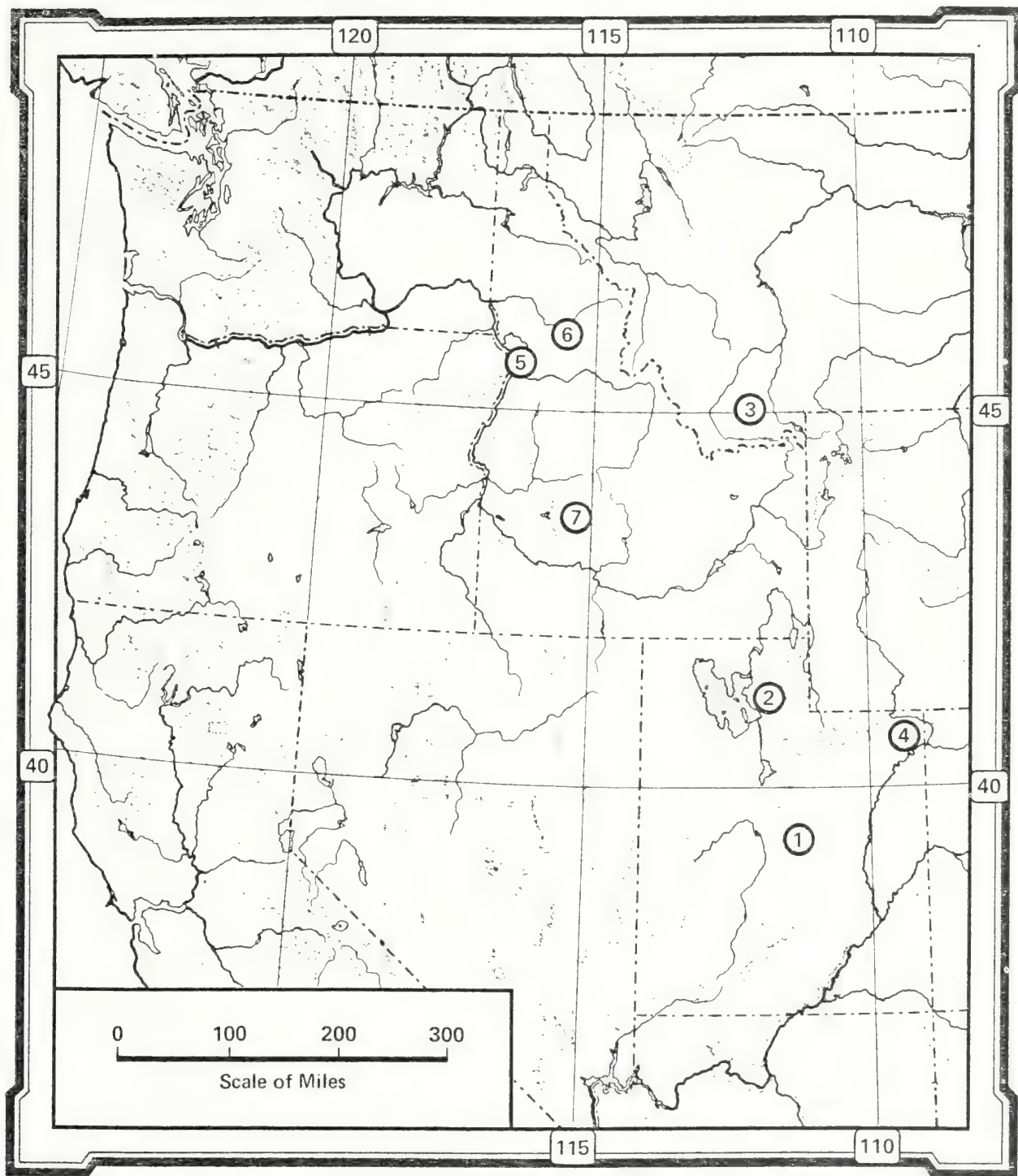


Figure 1.--Locations of the seven study areas.



6. *Coolwater Ridge*, Nezperce National Forest, central Idaho. Vegetation on this deteriorated subalpine range is predominantly low-value forbs. The granite-derived soils are sandy loam and loam. Plots were at about 6,000 feet.

7. *Trinity Mountains*, Boise National Forest, southern Idaho. Study plots were located in large and small openings in coniferous forest. The granitic soils, typical of much of the Idaho batholith, are sandy loams and loamy sands. Average elevation of plots was about 7,000 feet.

## MEASUREMENTS

*Sheet erosion*.--Simulated rain was applied to the 20- by 30.5-inch plots at a constant intensity of 5 inches per hour for 30 minutes, using the rainfall simulator described by Dortignac (1951). The raindrops produced by this simulator tend to be larger than those of natural high-intensity storms but possess less impact energy than natural rain because of their lower impact velocity. All water running off each plot was collected and the suspended sediment allowed to settle. This sediment, plus that deposited in the runoff-collecting trough at the bottom of the plot frame, was oven-dried and weighed.

*Initial soil moisture content*.--Immediately prior to the application of simulated rain, two 240 cc. soil samples were obtained adjacent to each plot in the surface 2 inches of soil. These samples were oven-dried to determine moisture content. To obtain a wider range of initial moisture conditions, half of the plots at each study site were prewet the day before the simulated rain test by applying 0.5 inch of simulated rain during a 15-minute period.

*Protective cover*.--Density and composition of cover on each plot were measured with a point frame (Levy and Madden 1933), using first strikes of 100 mechanically spaced pins to determine the proportions of the soil surface protected from direct rain-drop impact by plant species, litter, or stone. One or 2 days after the application of simulated rain, all vegetation and litter were removed from the plot, allowed to air-dry at least 2 weeks, and then weighed.

*Soil properties*.--Two days after application of the simulated rain, soil core samples were taken at the following depths: 0 to 1 inch, 1 to 2 inches, 2 to 4 inches, and 4 to 6 inches. Capillary porosity and bulk density of these soil cores were measured by the tension table method and subsequent oven-drying (Leamer and Shaw 1941). Soil organic matter contents at 0- to 1-inch and 1- to 2-inch depths were determined by the dichromate method (Peech, Alexander, Dean, and Reed 1947). Particle size distribution of the surface 1 inch of soil was measured by the hydrometer method (Bouyoucos 1962). Soil aggregation in the surface inch was measured by Middleton's (1930) method. In addition, Yoder's (1936) wet-sieving method was used to determine size distribution of water-stable aggregates in the surface inch of soil on the Davis County and Montana plots.

## ANALYSES

The data of this study were analyzed by multiple regression techniques. In all cases, the dependent variable ( $\hat{y}$ ) was the common logarithm of oven-dry weight (pounds per acre) of soil and organic material washed from the plot, including that deposited in the collector trough at the bottom of the plot frame. Logarithms were used because the erosion data were not normally distributed but were skewed to the right, that is, a large majority of the values were less than the mean. The logarithmically transformed data approached a normal distribution.

For each of the seven study areas, all measured site factors were evaluated for their contribution to explained variance by stepwise multiple regression analyses.



Many variables were found to be highly correlated with erosion but intercorrelation among most of these was also quite high. For each area, the most promising variables were chosen. In these analyses, the general objective was to reduce standard error to a minimum using, as much as possible, those variables most easily measured or estimated.

These analyses produced seven regression equations, one for each study area. Each of the following variables appears in at least one equation:

- A - Proportion of the soil surface protected from direct raindrop impact by vegetation and litter.
- B - Proportion of soil surface protected from direct raindrop impact by vegetation, litter, *and* stone.
- D - Sand content of the surface inch of soil (proportion by weight).
- E - Organic matter content of the surface inch of soil (proportion by weight).
- F - Organic matter content of the surface 2 inches of soil (proportion by weight).
- G - Slope gradient in percent.
- H - Bulk density of the surface 4 inches of soil (g./cc.).
- L - Air-dry weight of litter (pounds per milacre).

Of course, these are not the only variables that affect erosion. Most of the other measured variables had some effect on erosion but they did not explain sufficient additional variance to merit their inclusion in any multiple regression equations. For example, erosion was closely correlated with soil aggregation characteristics in some areas but the relations are rather complex and variable. Large water-stable aggregates resist erosion but stable aggregates smaller than 0.5-mm. diameter seemed to be more easily eroded than unaggregated material. Organic matter content served to explain as much, or more, variance as aggregation. When organic matter content was included in the equations, the additional variance explained by aggregation was small. Erosion was also affected by soil moisture content but these relations were also complex and variable. Some soils are more erodible when wet and some are more erodible when dry. Since surface soil moisture content was so variable, changed so rapidly, and generally had minor effects, it was not included in any of the final equations.

## RESULTS AND DISCUSSION

Without exception, protection of the soil surface from direct raindrop impact proved to be the most important means of controlling erosion on the study areas. On four of the study areas, the logarithm of soil eroded was more closely correlated with proportion of soil surface protected from raindrop impact by vegetation and litter than with any other measured variable. On the other three, the highest correlation was obtained with proportion of the soil surface protected by plants, litter, *and* stone. On these study areas, the presence of stone on soil surface not otherwise protected contributed significantly to protection against erosion. It is probable that stone had a protective influence in all cases but its effects were negligible on four of the seven areas, possibly because stone was not very prevalent on those areas or did not provide protection that was as effective as plants and litter.

The effects of plot slope gradient are important on all seven study areas and appear in all but one regression equation. This exception is the equation for an area where there were few observations and little variation in slope. The direct relation between erosion and slope tends to be greatest on the sandy soils.



Soil organic matter content appears in five of the equations. The favorable effects of organic matter in promoting aggregation of clay are well documented. However, the equations for the Diamond Mountain, Basalt, and Trinity study areas imply definitely adverse effects of organic matter on the stability of sandy soils; and it is expected that more intensive sampling would have revealed similar effects on Coolwater Ridge. It appears that while organic matter binds clay and silt particles into aggregates that resist erosion, it has an adverse effect on aggregation of sand particles. It is hypothesized that this adverse effect results from the hydrophobic character of organic coatings on sand particles, which causes the particles to resist wetting and, possibly, to possess mutual electrostatic repulsion, thus making the sand particles more easily detached and transported. No report of this phenomenon has been found in the literature but its occurrence in widely separated areas, as found in this study, indicates that it is not a mere coincidence, but an actual effect that should be recognized and investigated further.

The effects of cover, slope, organic matter content, and other site factors are discussed in detail for each study area in the following sections. Results on two of the study areas appear in other papers (Meeuwig 1969, 1970), but they are also presented here in a revised form to serve the purposes of this paper.

*Great Basin Experimental Area.*--In this area of calcareous fine-textured soils, bulk density was found to be the most important secondary factor affecting soil erosion. The proportion of soil surface protected from direct raindrop impact explains 52 percent of the variance of the log of soil eroded. Bulk density of the surface 4 inches of soil in combination with cover explains 62 percent of the variance. Plot slope gradient accounts for an additional 4 percent of the variance.

The regression equation for sheet erosion on this study area is:

$$\hat{y} = -3.12 - 0.618B - 2.50B^2 + 5.92H - 2.53H^2 + 1.44BH + 0.0221G$$

in which  $B$ ,  $H$ , and  $G$  are: protective cover (plant, litter, and stone); bulk density; and slope, as defined previously. This equation is based on 162 plots and has a coefficient of determination ( $R^2$ ) of 0.66. Its standard error of estimate is 0.38. Since the dependent variable is a logarithm, the standard error of estimate is also a logarithm and not easily interpreted. To overcome this difficulty, erosion as estimated by this equation is plotted logarithmically in figure 2 against erosion as actually measured.

The relation of erosion to protective cover and bulk density, as defined by this equation, is shown graphically in figure 3. Slope gradient was held constant at its average of 18 percent for the calculation of curves presented in figure 3. While cover percentage exerts the major controlling influence on the weight of soil eroded, soil bulk density has an important influence. At any fixed cover percentage the amount of soil eroded is about twice as great at a bulk density of 1.1 g./cc. as it is at 0.9 g./cc. Bulk density influences erosion because aggregation and porosity are inversely related to bulk density. Well-aggregated soils tend to have low bulk densities and they also tend to resist erosion. Soils of high porosity have good infiltration characteristics and, consequently, produce less overland flow and erosion.

Correction factors for deviations of slope gradients from an average of 18 percent are tabulated in table 1. Weights of soil eroded in figure 3 should be multiplied by the appropriate factor in table 1 to correct for slope effects. At any given cover percentage and bulk density, the amount of erosion is about 3 times greater on 40 percent slopes than on 18 percent slopes.



Figure 2.--Estimated versus actual soil erosion on the Great Basin Experimental Area.

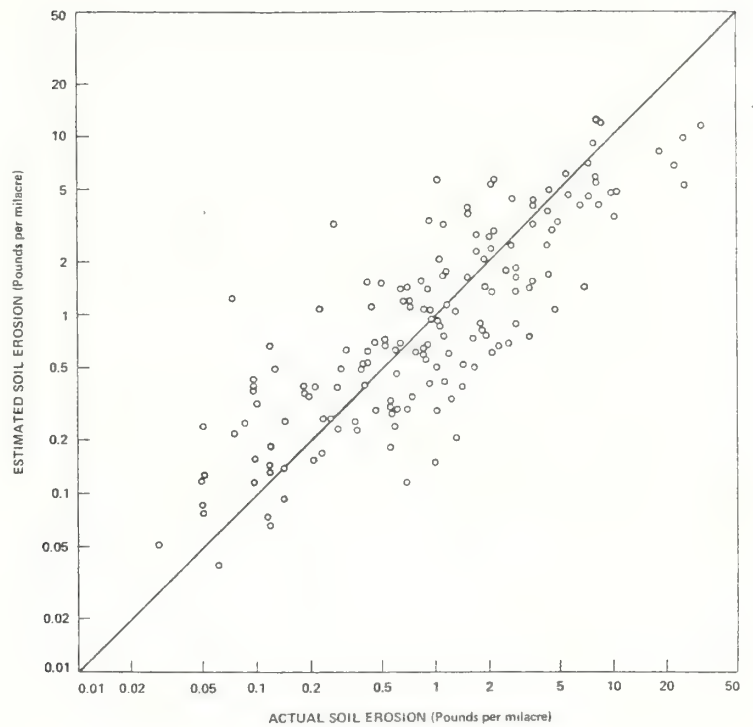


Figure 3.--Soil erosion on the Great Basin Experimental Area in relation to percent of soil surface protected from direct raindrop impact at bulk densities of 0.9, 1.1, and 1.3 g./cc.

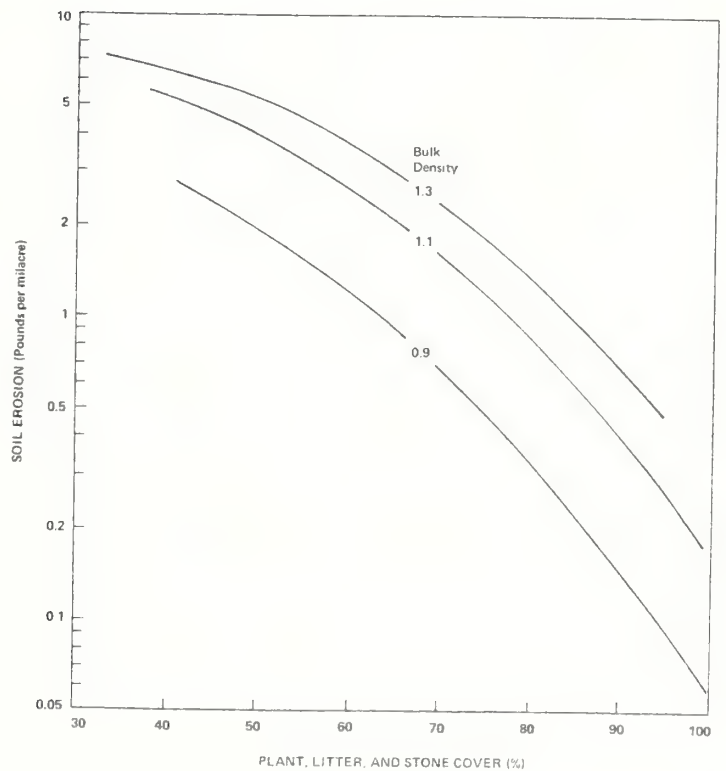




Table 1.--Correction factors for slope gradient

Study area:	Slope gradient (%)							
	5	10	15	20	25	30	35	40
GBEA	0.52	0.66	0.86	1.11	1.43	1.84	2.37	3.06
DCEW	.51	.64	.80	1.00	1.25	1.56	1.95	2.44
Montana	.69	.81	.94	1.10	1.28	1.49	1.73	2.02
Diamond	.64	1.00	1.55	2.41	3.75	--	--	--
Basalt	.57	.70	.88	1.09	1.35	1.69	2.10	2.61
Trinity	.38	.49	.65	.86	1.11	1.46	1.91	2.51

*Davis County Experimental Watershed.*--Protective cover provided by plants and litter explains 76 percent of the variance in the log of soil eroded from study plots on this area. Three other site factors about equal in secondary importance are: slope gradient; litter weight; and soil organic matter. These, in combination with cover density, account for 83 percent of the variance.

The regression equation for sheet erosion on this study area is:

$$\hat{y} = 0.858 - 0.176A - 1.81A^2 - 0.117L + 0.0511AL - 5.89F + 0.0193G$$

in which *A*, *L*, *F*, and *G* are: plant and litter cover; litter weight; soil organic matter content; and slope gradient defined in the analyses section of this paper. This equation is based on 79 plots and has a standard error of estimate of 0.44 (fig. 4).

Sheet erosion as a function of plant and litter cover and litter weight is shown in figure 5. The amount of erosion is governed primarily by the proportion of soil surface protected by plants and litter but the actual weight of litter has an additional favorable influence in retarding erosion.

The curves of figure 5 are based on the above equation with organic matter content at its average of 6 percent and slope gradient at its average of 20 percent. Correction factors for variation of organic matter content of the surface 2 inches of soil are given in table 2. To correct for organic matter content variation, the soil erosion values in figure 5 should be multiplied by these factors. At an organic matter content of 11 percent, the amount of erosion is about one-half that indicated by figure 5; but if organic matter content is only 1 percent, erosion is almost twice that shown in figure 5. In like manner, corrections for slope can be obtained from table 1.

Table 2.--Correction factors for organic matter content in the surface 2 inches of soil on the Davis County Experimental Watershed

Organic matter (% by weight)	Correction factor	Organic matter (% by weight)	Correction factor
1	1.97	7	.87
2	1.72	8	.76
3	1.50	9	.67
4	1.31	10	.58
5	1.15	11	.51
6	1.00	12	.44



Figure 4.--Estimated versus actual soil erosion on the Davis County Experimental Watershed.

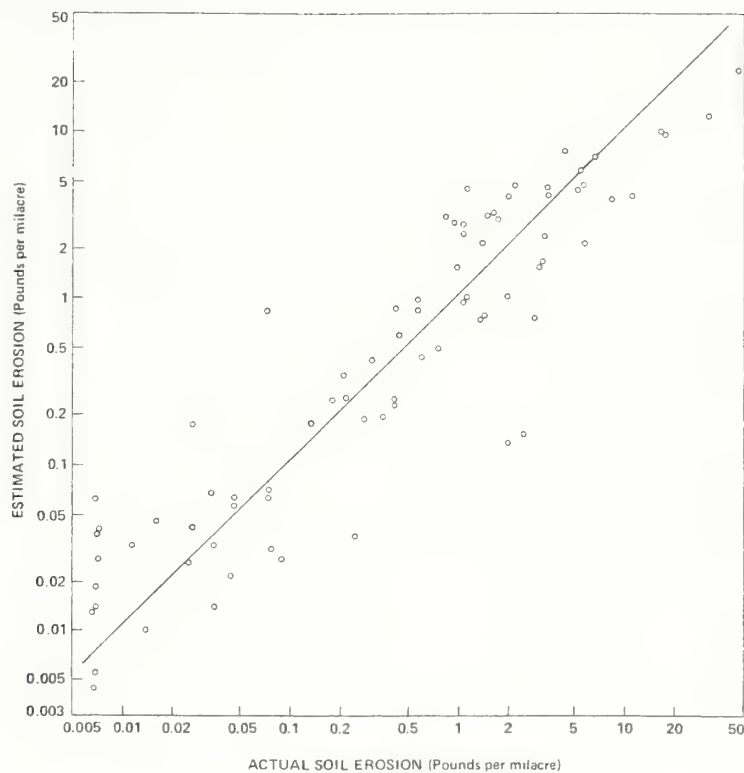
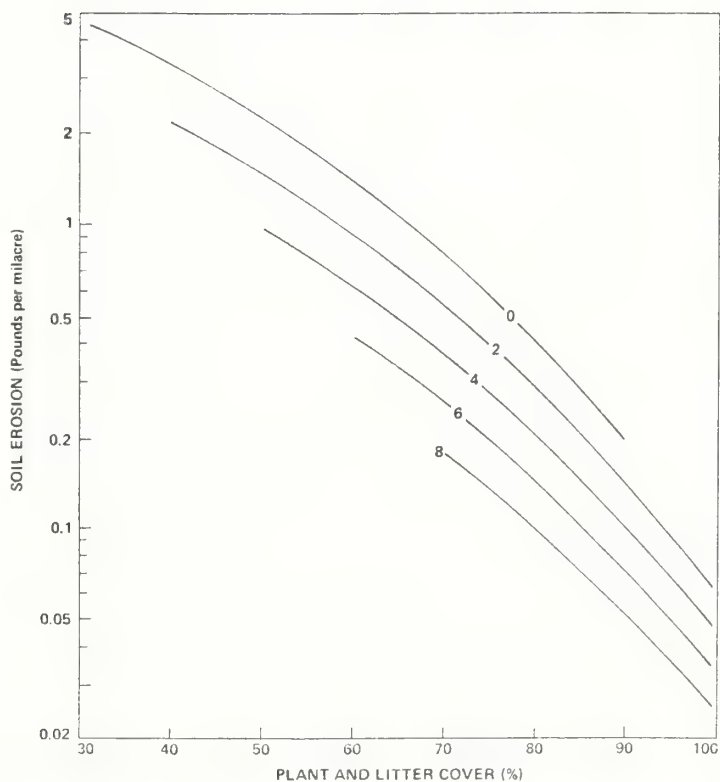


Figure 5.--Soil erosion on the Davis County Experimental Watershed in relation to percentage of soil surface protected from direct raindrop impact by plants and litter at litter weights of 0, 2, 4, 6, and 8 pounds per milacre.





*Vigilante Experiment Range and Monument Ridge, Montana.*--Plant and litter cover explains 80 percent of the variance of the log of soil eroded from plots on this study area. Organic matter content of the surface inch of soil also favors resistance to erosion, probably through aggregation of soil particles, and explains an additional percent of the variance. Slope gradient explains an additional 2 percent of the variance.

The regression equation for this study area is:

$$\hat{y} = 1.563 - 0.629A - 1.86A^2 - 26.0F + 13.2F^2 + 19.0AF + 0.0133G$$

This equation is based on 86 plots and has a standard error of estimate of 0.33 and a coefficient of determination of 0.86 (fig. 6). Sheet erosion as a function of plant and litter cover and organic matter content of the surface 2 inches of soil is shown in figure 7. Correction factors for deviation of slope gradient from its average of 17 percent are in table 1.

*Diamond Mountain.*--The three most important site variables on this study area are plant and litter cover; organic matter content of the surface inch of soil; and slope gradient. The effects of cover are similar to those found on the other study areas, but the effect of slope is greater than on the other study areas. Unlike the previous three areas, organic matter content is positively correlated with erosion. The regression equation for sheet erosion developed from Diamond Mountain data is:

$$\hat{y} = -1.015 + 1.31A - 2.08A^2 - 5.87AE + 8.13E + 0.0383G$$

This equation is based on 34 observations. Its standard error of estimate is 0.32 and its  $R^2$  is 0.71 (fig. 8). With slope gradient fixed at its average of 10 percent, this equation is presented graphically in figure 9.

Figure 6.--Estimated versus actual soil erosion on the Montana study area.

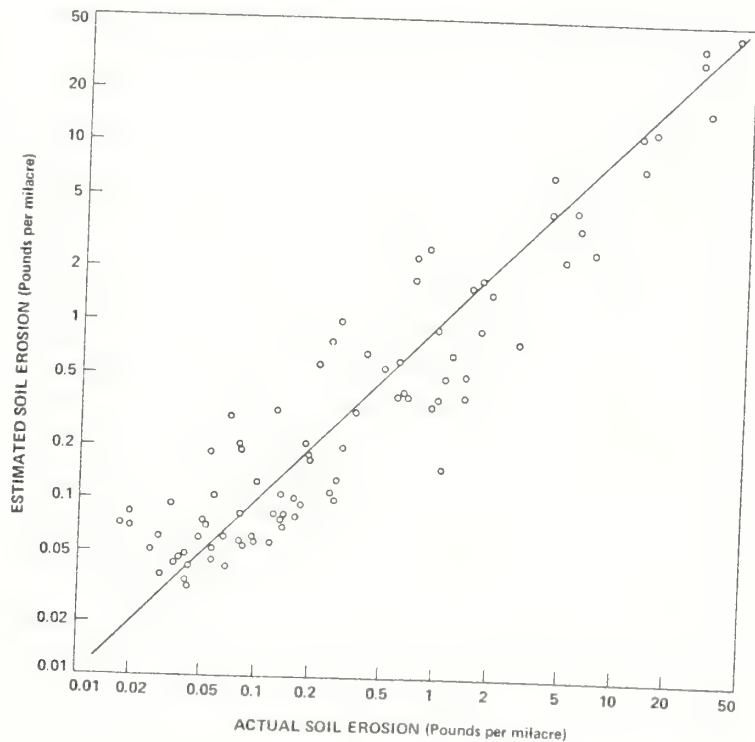




Figure 7.--Soil erosion on the Montana study area in relation to percentage of soil surface protected from direct raindrop impact by plants and litter at 2, 6, 10, and 14 percent organic matter in the surface 2 inches of soil.

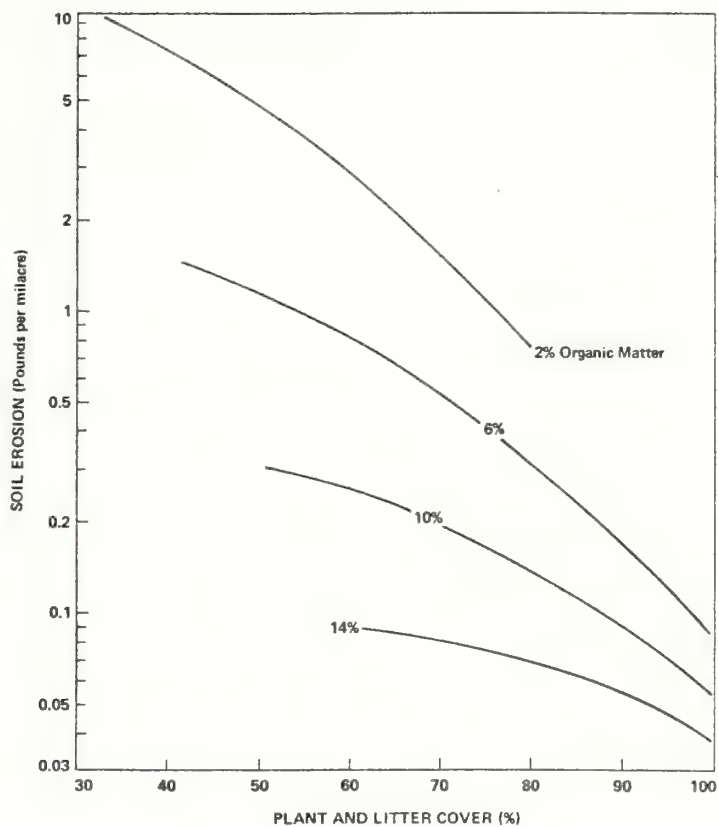


Figure 8.--Estimated versus actual soil erosion on the Diamond Mountain study area.

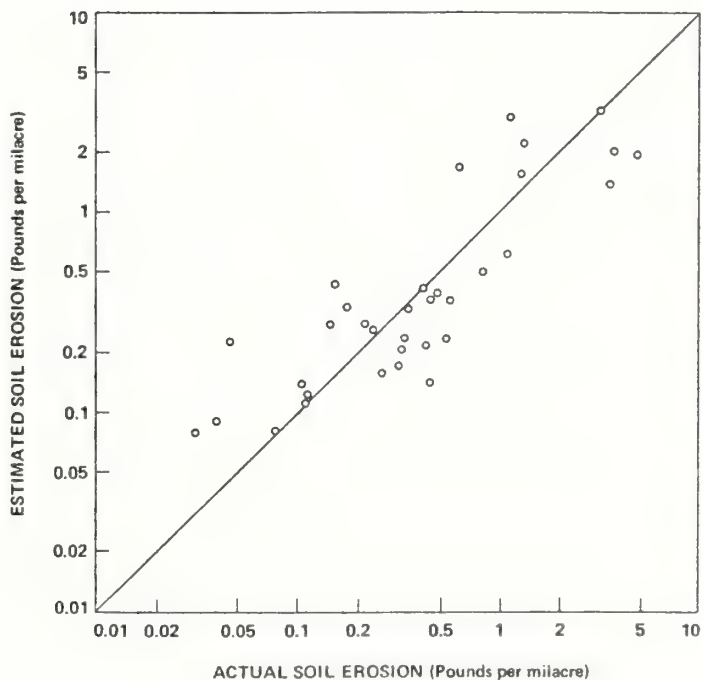
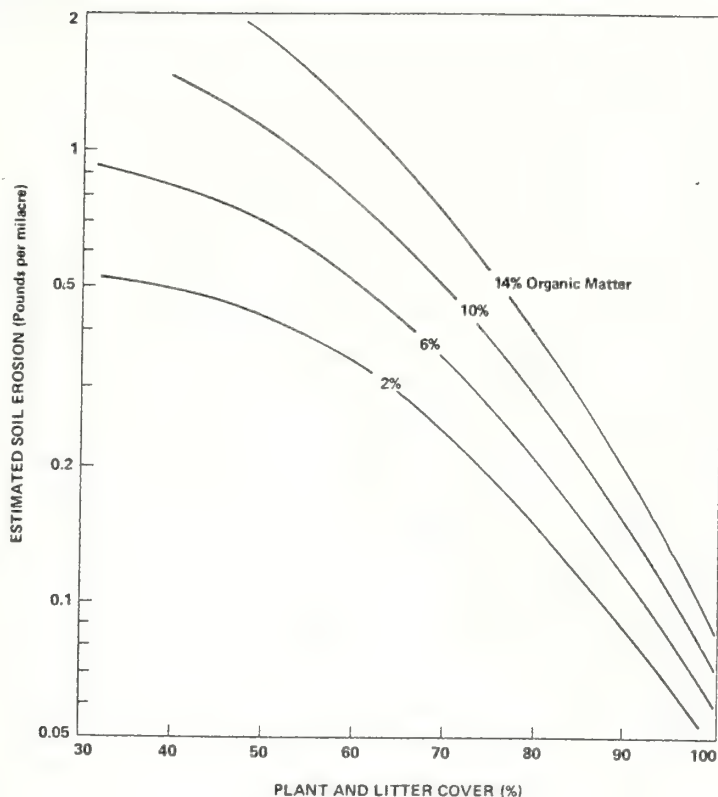




Figure 9.--Soil erosion on the Diamond Mountain study area in relation to percentage of soil surface protected from direct raindrop impact by plants and litter with 2, 6, 10, and 14 percent organic matter in the surface inch of soil.



The striking feature of this equation is that the amount of erosion increases as organic matter content increases. This is contrary to results of studies on finer textured soils where organic matter favors the formation of erosion-resistant aggregates. One would suspect spurious correlation if this positive relation between erosion and organic matter content were observed only on this study area. However, similar relations were observed on other coarse-textured soils in Idaho, up to 500 miles from this study area.

*Basalt.*--The strong interaction between sand content and organic matter content was quite apparent on this area. The regression equation for sheet erosion on this study area is:

$$\hat{y} = 6.615 - 3.58B + 1.50B^2 - 19.7D + 15.0D^2 - 41.4E + 92.7DE + 0.0189G$$

This equation is based on 44 plots and has a standard error of estimate of 0.39 and a coefficient of determination of 0.69 (fig. 10). Protective cover provided by plants, litter, and stone (fig. 11) is the most important variable and the effects of slope gradient (table 1) were similar to those on other study areas. The curve in figure 11 is based on average slope (18 percent), average sand content (38 percent), and average organic matter content (9 percent). The effects of variations of sand and organic matter are shown graphically in figure 12. Where sand contents are low, erosion decreases sharply as organic matter increases. But organic matter apparently had a reverse effect on erosion where sand contents are high, an effect similar to that observed at Diamond Mountain. In soil having a 45 percent sand content, organic matter has little influence on erosion, probably because its aggregating influence on clay is compensated by its unfavorable influence on erodibility of sand.

The net effect is that the fine-textured soils are more erodible if there is little organic matter in the surface soil but, when there is much organic matter, sheet erosion is greater on sandy soils.



MEEUWIG RICHARD O.

1970. Sheet erosion on intermountain summer ranges, USDA Forest Serv. Res. Pap. INT-85, 25 p., illus.

Simulated rain was applied to small plots on seven mountain rangeland sites in Utah, Idaho, and Montana. The magnitude of soil erosion was found to depend primarily on the proportion of the soil surface protected from direct raindrop impact by plants, litter, and (in some cases) stone. Soil organic matter favored stability of fine-textured soils, but apparently increased erodibility of sandy soils.

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Figure 10.--Estimated versus actual erosion on the Basalt study area.

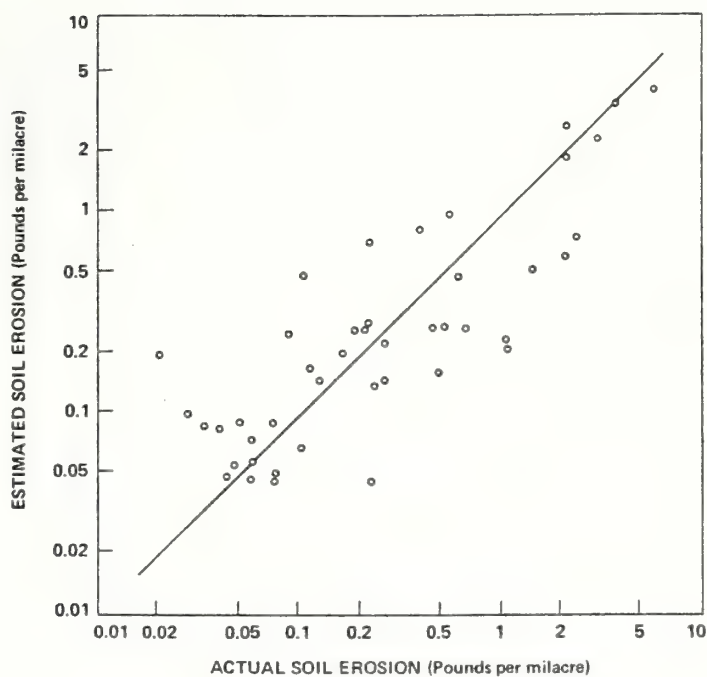


Figure 11.--Soil erosion on the Basalt study area in the relation to percent of soil surface protected from direct raindrop impact when the surface inch of soil contains 38 percent sand and 9 percent organic matter.

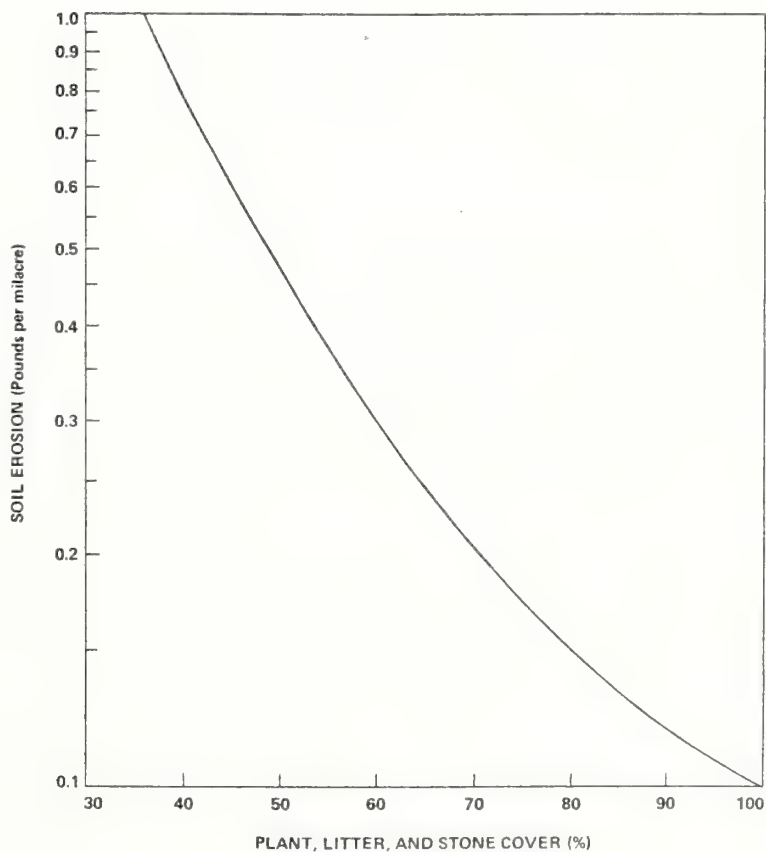
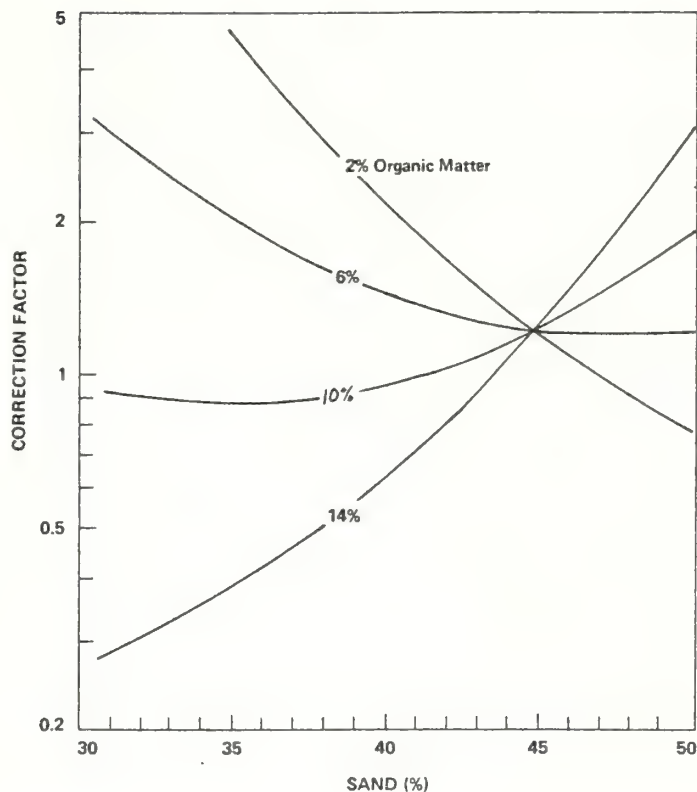




Figure 12.--Effects of changes in sand and organic matter content on amount of soil erosion on the Basalt study area. Soil erosion indicated in figure 11 should be multiplied by correction factor indicated in figure 12 to correct for variations in soil organic matter content and sand.



*Coolwater Ridge.*--Plant, litter, and stone cover explains 83 percent of the variance in the log of soil eroded. No significant additional variance was explained by any other variable, probably because of the few plots (15) and the limited variation in these other variables. The following equation has a standard error of 0.32:

$$\hat{y} = 1.293 + 0.105B - 2.04B^2$$

The curve defined by this equation is plotted in figure 13 along with the data. Erosion is generally greater at Coolwater Ridge than on the other study areas because of rather steep slopes (33 percent average) and a high sand content (57 percent average) combined with a rather high organic matter content (10 percent average). Observations on other study sites indicate that high organic matter content and steep slopes both operate to increase erosion on sandy soils. Another reason for greater erosion at Coolwater Ridge may be due to the character of the vegetation which consists mainly of low-value forbs such as polygonum. This type of vegetation, with its small basal area and low litter production, gives less protection against erosion than an equal areal coverage of grasses or mat-forming forbs.

*Trinity Mountains.*--The erosional behavior of these granitic soils is rather erratic. Only about 45 percent of the variance of the log of soil eroded is accounted for by plant and litter cover. The influence of cover on erosion is greatest on soils of high organic matter content. The multiple regression equation is:

$$\hat{y} = -0.666 + 1.71A - 1.82A^2 + 8.60E - 18.0AE + 0.0235G$$

This equation is based on 40 plots. The standard error of estimate for this equation is 0.40 but the coefficient of determination is only 0.57 (fig. 14). With plot slope gradient fixed at its average of 23 percent, this equation is presented



Figure 13.--Soil erosion on the Coolwater Ridge study area in relation to percent of soil surface protected from direct rain-drop impact.

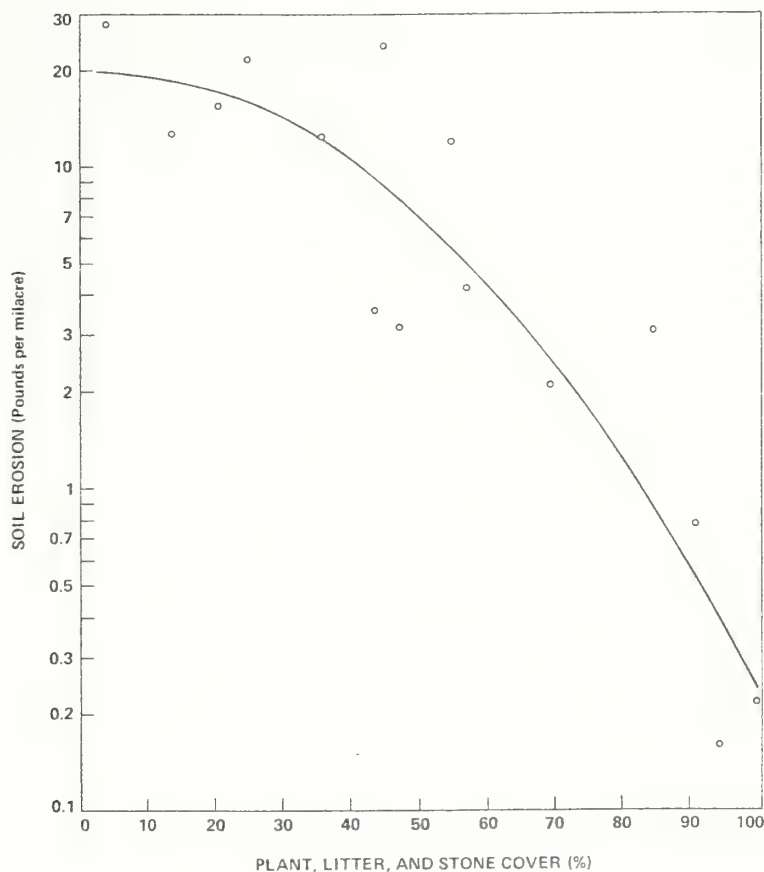


Figure 14.--Estimated versus actual soil erosion on the Trinity Mountains study area.

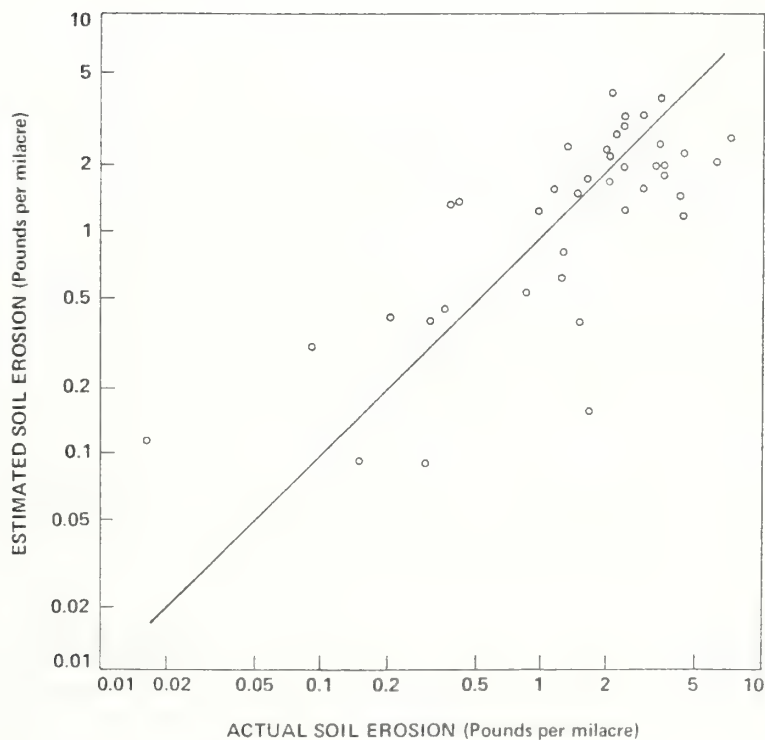
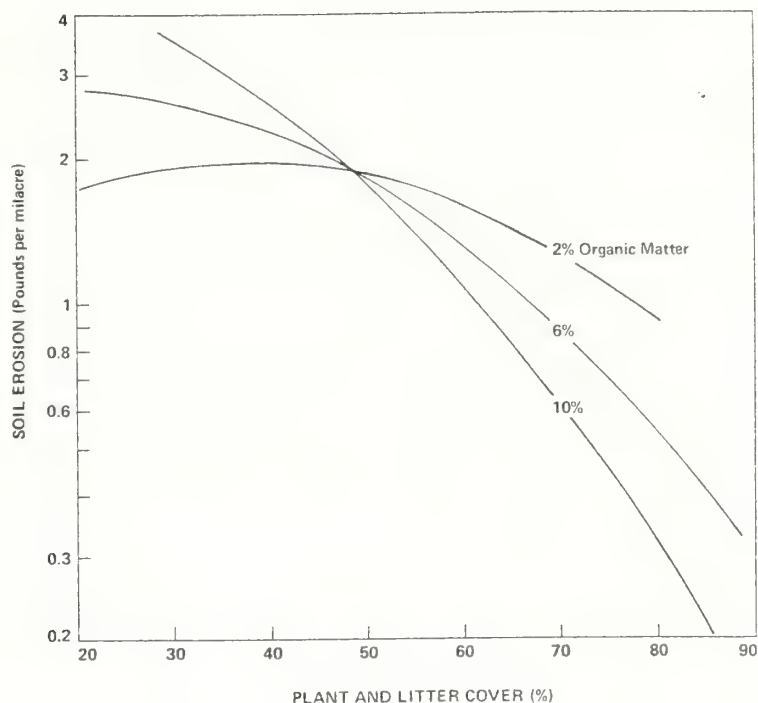




Figure 15.--Soil erosion on the Trinity Mountains study area in relation to percent cover of plant and litter at 2, 6, 10 percent organic matter in the surface inch of soil.



graphically in figure 15. When more than 50 percent of the soil surface is protected by vegetation and litter, organic matter favors resistance to erosion. At less than 50 percent cover, there is a reversal of this influence and a tendency for the more highly organic soils to be more erodible. This is an important consideration because the average plant and litter cover on the plots in this study area was only 52 percent and organic matter content averaged 6 percent, a high organic matter content for soils averaging 72 percent sand.

Since this equation accounts for only 57 percent of the variance, there are obviously other factors affecting erosion on this site. Further study is needed, particularly on inorganic bonding between sand particles and on the nature of the adverse effects of organic matter on stability of sandy soils.

## APPLICATION

The regression equations presented in this paper may be used to estimate the amount of sheet erosion expected under design rainstorm conditions. These estimates are relative values to be used for comparisons among sites. The equations are derived from small plots with a fixed amount of simulated rain and cannot be expected to yield absolute estimates of erosion because variations in rainfall characteristics and plot size will influence the actual amount of erosion.

Since direct solution of the equations is tedious unless a computer is available, tables and nomograms are provided in the Appendix to facilitate calculations. Coolwater Ridge is not included because its equation is based on too few observations to be useful for estimation.

Estimates may be made for areas other than those studied only if there is reasonable assurance that the area in question closely resembles one of the study areas and



the equation for that study area is used. Obviously, the uncertainty of the estimate increases as the difference between the area of application and the original study area increases.

The accuracy of the estimates can be improved by considering some site factors that do not appear in the equations but still may influence amount of erosion.

On most of the plots in this study, the cover was fairly uniform in distribution. If cover is not uniformly distributed, as on bunchgrass range, estimates of erosion will probably be low; the size of bare openings can affect erosion significantly (Packer 1951).

Basal area of vegetation is another factor that should be considered. Although protection from direct rainfall impact is likely the most important single function of vegetation, the amount of cover in direct contact with the ground is also important. At any given areal cover percentage, those species having a larger basal area will retard overland flow and erosion more than those with a smaller basal area. In this respect, grasses are superior to tall, single-stem forbs.

On finer textured soil, litter weight apparently exercises some restrictive influence on erosion in addition to that attributable to protection from direct raindrop impact. On sandy soils, litter appears to have no favorable influence beyond that of raindrop interception.

The erodibility of the litter itself must also be considered. It may be eroded if it consists of small, easily detached fragments. Erosion tends to be greater on sites with easily detached litter than on otherwise similar sites with firmly anchored litter.

Bulk density occasionally influences erosion but these effects are complex. There is an inverse relation between bulk density and infiltration because soil porosity is inversely related to bulk density; this means more runoff and, consequently, more erosion on denser soils. There is also an inverse relation between bulk density and organic matter content; and, as noted earlier in this paper, organic matter exercises a variable effect on erosion, depending on soil texture. Under some circumstances, and this was noted particularly on sandy soils, cohesiveness and resistance to detachment are positively related to bulk density; some light fluffy soils are highly erodible.

While it is obvious that soil erodibility depends on many factors, results of this study suggest that reliable estimates of erodibility may be made on the basis of a few of the most important ones. The equations in this paper give reasonable approximations of the amount of sheet erosion that will occur on any particular site under the impact of a half-hour simulated design rainstorm. These approximations, augmented by visual observations in the field, provide bases for estimating potential sheet erosion on sites similar to those studied.



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## APPENDIX

*Great Basin Experimental Area.*--Estimated sheet erosion on GBEA as a function of bulk density (surface 4 inches of soil) and total cover percentage (plants, litter, and stone) is listed in table 3. For example, if a site has 60 percent cover and bulk density is 1.05 g./cc., the estimate is 2.16 pounds per milacre, without slope correction. If the slope gradient of this site is 10 percent, the correction factor is 0.66 (from table 1). Estimated erosion, corrected for slope, is  $2.16 \times 0.66 = 1.4$  pounds per milacre.

*Davis County Experimental Watershed.*--The nomogram (fig. 16) for DCEW is used as follows:

1. Start at plant and litter cover percentage on line A and draw a line to litter weight (lbs./milacre) on line B.
2. Draw a line from the intersection point on line C to slope percentage on line D.
3. Draw a line from the intersection point on line E to organic matter percent on line F.
4. The intersection on line G is estimated erosion in pounds per milacre.

For example, if a site has 80 percent cover of plants and litter, 4 pounds of litter per milacre, 36 percent slope, and 8.1 percent organic matter in the surface 2 inches of soil, its estimated sheet erosion is 0.30 pound per milacre according to figure 16.

Table 3.--*Sheet erosion on GBEA as affected by total cover (plants, litter, and stone) and soil bulk density (surface 4 inches)*

Cover (%)	Bulk density (g./cc.)								
	0.90	0.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30
----- Pounds per milacre -----									
30	3.40	4.11	4.84	5.53	6.14	6.62	6.93	7.05	6.96
35	3.05	3.72	4.42	4.98	5.69	6.20	6.53	6.71	6.68
40	2.65	3.27	3.91	4.54	5.12	5.62	5.98	6.18	6.21
45	2.25	2.79	3.36	3.95	4.48	4.96	5.32	5.54	5.62
50	1.85	2.31	2.81	3.32	3.81	4.25	4.60	4.83	4.93
55	1.48	1.87	2.28	2.72	3.15	3.56	3.86	4.09	4.21
60	1.14	1.46	1.80	2.16	2.52	2.86	3.15	3.36	3.49
65	.86	1.12	1.38	1.68	1.97	2.25	2.50	2.70	2.81
70	.63	.82	1.02	1.16	1.49	1.72	1.92	2.09	2.20
75	.45	.59	.74	.92	1.10	1.28	1.44	1.57	1.68
80	.31	.41	.52	.65	.78	.92	1.05	1.15	1.24
85	.21	.28	.36	.44	.55	.65	.75	.82	.89
90	.14	.18	.24	.30	.37	.44	.51	.57	.62
95	.09	.12	.15	.20	.24	.29	.34	.39	.43
100	.05	.07	.10	.12	.15	.19	.22	.25	.28



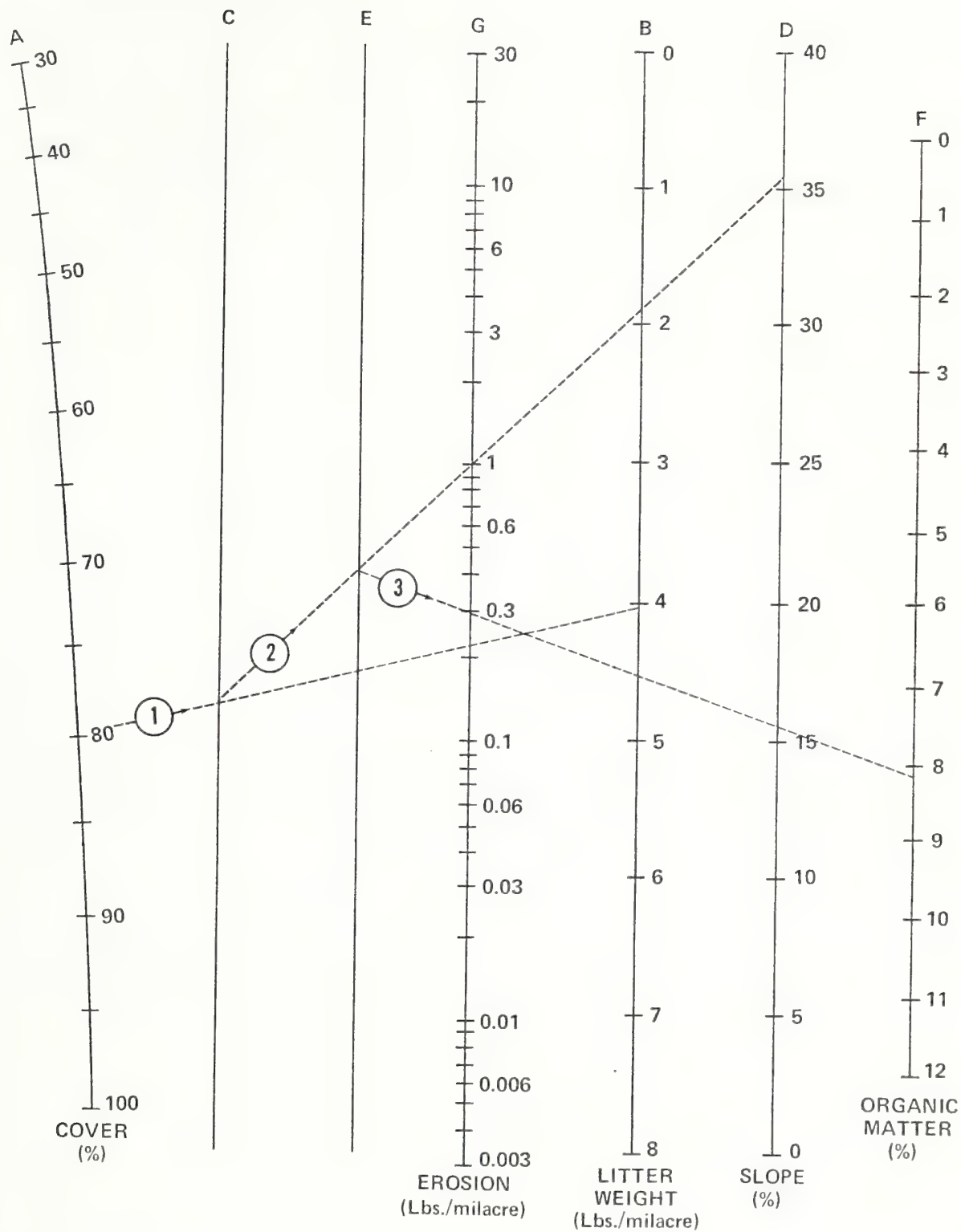


Figure 16.--Nomogram for estimating sheet erosion on the Davis County Experimental Watershed.



Table 4.--*Estimated sheet erosion on Monument Ridge and the Vigilante Experimental Range as a function of plant and litter cover and organic matter content of the surface 2 inches of soil*

Cover (%)	Organic matter content (% by weight)					
	2	4	6	8	10	12
----- Pounds per milacre -----						
30	10.78	4.39	1.83	.78	--	--
35	9.11	3.88	1.69	.76	.35	--
40	7.53	3.35	1.53	.71	.34	--
45	6.10	2.83	1.35	.66	.33	--
50	4.83	2.35	1.17	.59	.31	.17
55	3.75	1.90	.99	.53	.29	.16
60	2.85	1.51	.82	.46	.26	.15
65	2.11	1.17	.66	.39	.23	.14
70	1.54	.89	.53	.32	.20	.13
75	1.09	.66	.41	.26	.17	.11
80	.76	.48	.31	.21	.14	.10
85	.52	.34	.23	.16	.11	.08
90	.35	.24	.17	.12	.09	.07
95	.23	.16	.12	.09	.07	.06
100	.14	.11	.08	.07	.05	.04

*Monument Ridge and Vigilante Experimental Range.*--Table 4 lists estimated sheet erosion as a function of plant and litter cover and organic matter content of the surface 2 inches of soil. These values should be multiplied by the appropriate correction factor in table 1 to correct for slope.

*Diamond Mountain.*--The nomogram (figure 17) for the Diamond Mountain Cattle Allotment is used as follows:

1. Draw a line from the plant and litter cover percentage on line A to the organic matter content of the surface inch of soil on line B.
2. Draw a line from the intercept on line C to the slope gradient on line D.
3. The intersection on line E is estimated sheet erosion.



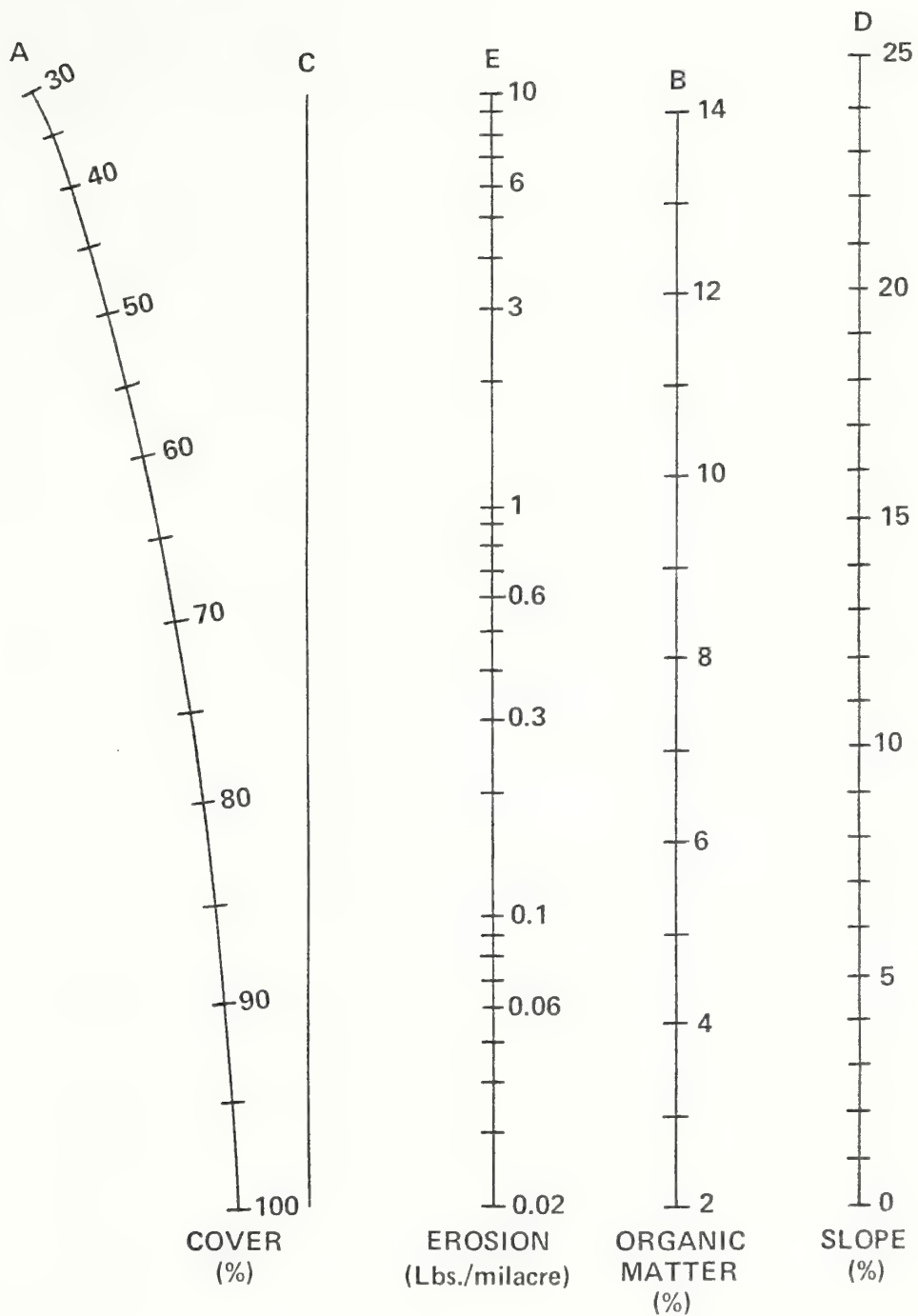


Figure 17.--Nomogram for estimating sheet erosion on the Diamond Mountain study area.



*Basalt.*--Three tables (1, 5, and 6) are required to calculate estimated erosion on the Basalt study area. Table 5 lists erosion as a function of plant, litter, and stone cover percent. Table 6 contains correction factors for sand and organic matter content of the surface inch of soil. For example, a site has 80 percent cover, 40 percent sand, 10 percent organic matter, and a 30 percent slope. Table 5 indicates sheet erosion to be 0.15 pound per milacre, uncorrected for slope or soil. Table 1 indicates a slope correction of 1.69. Table 6 indicates a soil correction of 0.92. Therefore, estimated sheet erosion is:  $0.92 \times 1.69 \times 0.15 = 0.23$  pound per milacre.

*Trinity Mountains.*--The nomogram (fig. 18) for this study area is used as follows:

1. Draw a line from the plant and litter cover percentage on line A to the organic matter content of the surface 1 inch of soil on line B.
2. Draw a line from the intercept on line C to the slope gradient on line D.
3. The intersection on line E is estimated sheet erosion.

Table 5.--*Estimated sheet erosion on the Basalt study area as related to protective cover provided by plants, litter, and stone*

Cover (%)	Erosion (lbs./milacre)	Cover (%)	Erosion (lbs./milacre)
30	1.36	70	.20
35	1.15	75	.17
40	.76	80	.15
45	.58	85	.13
50	.45	90	.12
55	.36	95	.11
60	.29	100	.10
65	.24		

Table 6.--*Correction factors for sand and organic matter content in the surface inch of soil on the Basalt study area*

Sand (%)	Organic matter content (% by weight)							
	2	4	6	8	10	12	14	16
30	--	--	3.17	1.69	0.91	0.49	0.26	0.14
32	--	4.34	2.53	1.48	.86	.50	.29	.17
34	5.15	3.27	2.08	1.32	.84	.53	.34	.22
36	3.67	2.54	1.76	1.22	.84	.58	.40	.28
38	2.68	2.02	1.53	1.15	.87	.65	.49	.37
40	2.02	1.66	1.36	1.12	.92	.75	.62	.51
42	1.56	1.40	1.25	1.12	1.00	.89	.80	.71
44	1.24	1.21	1.18	1.15	1.12	1.09	1.06	1.03
46	1.02	1.08	1.14	1.21	1.28	1.36	1.45	1.54
48	.85	.99	1.14	1.32	1.52	1.76	2.03	--
50	.74	.93	1.17	1.47	1.85	2.33	--	--



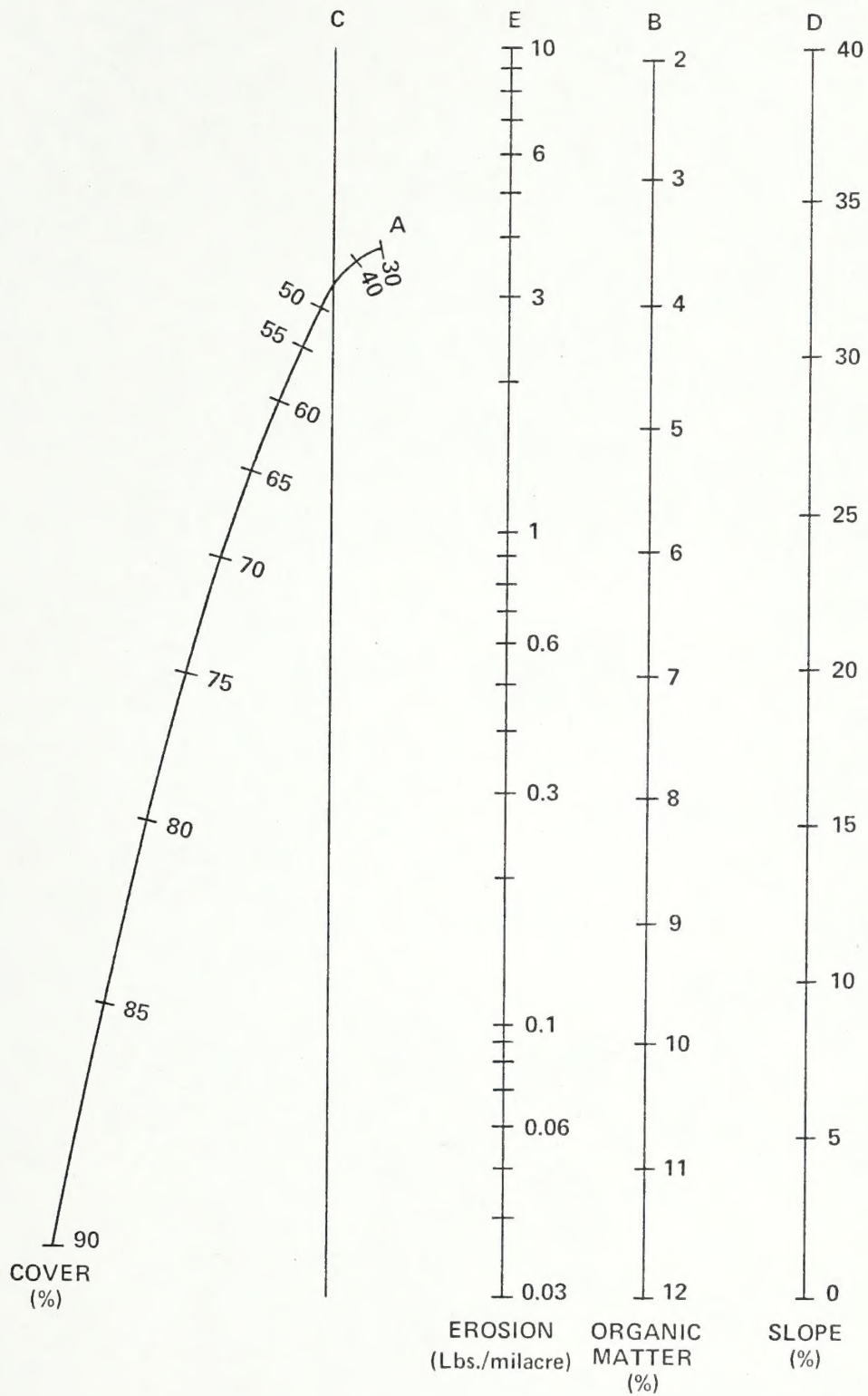


Figure 18.--Nomogram for estimating sheet erosion on the Trinity Mountains study area.



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